

**A SYSTEM AND METHOD FOR DETERMINING DEPENDENCIES BETWEEN
SYSTEM RESOURCE PERFORMANCE CHARACTERISTICS**

Field of the Invention

5

The present invention relates to a system and method for determining dependencies between system resource performance characteristics in a computing system.

10 **Background of the Invention**

Transaction processing systems, such as enterprise class computer systems and e-commerce servers, require monitoring and analysis in order to ensure efficient
15 utilisation of hardware resources. That is, it is desirable to maximise the number of transactions processed by a computing system within a given time.

Generally, in monitoring and analysing the hardware and software resource usage of a computing system, a
20 system monitor will generally observe and record characteristics of the transaction load and other characteristics of system behaviour. The data gathered by the monitor is used by users (such as system administrators) to identify problem areas and reduce
25 performance bottlenecks.

For example, a system administrator will generally attempt to balance system load flow between system elements, by, for example, switching off less essential services to provide more resources to critical services.

30 In order to make an informed decision on how to balance load or change the operating parameters of a computing system, a system administrator will generally be provided with a large number of characteristics that are monitored by the computing system. These characteristics
35 are generally monitored by "counters", which are generally software modules which collect statistics on the performance of various hardware and software sub-systems

within a computing system.

A typical server will have over a thousand counters, each counter describing a different aspect of system behaviour. The counters may include characteristics such
5 as processor (CPU) utilisation, interrupt rate, memory usage, number of disk reads within a given time, and number of disk writes within a given time.

In the art, the abovementioned counters are commonly split into two general "types".

10 The first type of counter is utilised for system monitoring. These counters are generally associated with on-line display of counter values. The WindowsTM operating system performance monitor "perfmon" and the "sar" software package on UnixTM operating system are examples of
15 software packages that monitor the first type of counters.

The second counter type is generally employed for system analysis. That is, these counters are generally employed off-line, for analysis of daily and weekly patterns of load, response time, and gauging the effect of
20 hardware and/or software upgrades.

Whilst these two types of counters utilise different methodologies, they attempt to achieve the same aim, namely to provide an indicator of how computer resources are utilised within a computing system.

25 Existing tools provide no mechanism to organise the large number of counters ("characteristics") present in contemporary computer systems. Existing tools are capable of displaying any required characteristic, but do not offer any guidance to the system administrator as to which
30 characteristics are important. That is, the system administrator has to specify which characteristics they wish to monitor and/or analyse.

Traditionally, characteristics selected for monitoring/analysis are chosen on the basis of whether
35 they are "thought" to be important. For example, it is generally held by persons skilled in the art that the daily average CPU utilisation and the daily average

throughput are important characteristics that should be monitored closely.

By employing such a methodology, hundreds or potentially thousands of other characteristics are ignored, primarily because it is too time consuming to monitor or analyse every system characteristic. In order to ameliorate this problem, some contemporary monitoring tools allow the user to set an alarm for a particular counter. The alarm will alert the system administrator when the value of the counter passes a predetermined value. This approach provides some indication of which characteristics should be displayed and/or analysed, but still requires system administrators to manually configure the alarm levels. As there are potentially thousands of separate counters, many system administrators will not set alarm levels for each characteristic. Therefore, this system of providing alarm levels does not satisfactorily solve the problem.

In addition, some contemporary monitoring tools allow for two selected characteristics to be plotted against each other. Once again, the system administrator is required to select which characteristics they wish to view. Thus, this feature does not ameliorate the problem of determining which characteristics are important to a computing system.

Similarly, it is difficult for the producers of monitoring tools to predict and pre-select system characteristics which will be of particular importance on a defined computing system. For some computing systems, the important characteristic may be processor time, for some it may be disk access time.

In addition, different computing systems will have different daily usage profiles and application mixes, so each computing system will require individual customisation. However, during the installation and customisation phase, it is easy to accidentally omit characteristics which are important for a given

installation. For example, the number of context switches per second, a counter which is rarely examined, may be important for a particular computing system.

5 In other words, the problem of determining which characteristics are important to a particular computing system is circular. The user is required to know which counters should be included to adequately analyse the system, yet to analyse the system, the correct counters must be specified to ensure adequate data collection.

10 Moreover, despite careful initial analysis, the dynamic nature of system load frequently results in a situation where new characteristics become important only during certain periods of time.

15 There is a need to provide a system or method which assists the system administrator in determining which system performance characteristics are important for a given computing system.

Summary of the Invention

20 In a first aspect, the present invention provides a method for analysing a computing system comprising the step of determining a dependency between a first and a second system resource performance characteristic in a computing system, the step of determining the dependency including the steps of:

providing data values for the first performance characteristic and the second performance characteristic of the computing system; and

30 applying a mathematical algorithm to derive a correlation value between the first and second characteristics,

wherein the correlation value provides an indication of the relative association between the second characteristic and the first characteristic.

35 The present invention advantageously allows an operator or system administrator to determine which

characteristics of a computing system are important.

Preferably, the mathematical algorithm is the Pearson correlation coefficient equation.

In a second aspect, the present invention provides a
5 method of determining sub-optimal performance in a
computing system, comprising the steps of,

determining a dependency between a first and a second
system resource performance characteristic in a computing
system, the step of determining the dependency including
10 the steps of:

providing data values for the first performance
characteristic and the second performance characteristic
of the computing system; and

applying a mathematical algorithm to derive a
15 correlation value between the first and second
characteristics,

wherein the correlation value provides an indication
of the relative association between the second
characteristic and the first characteristic.

In a third aspect, the present invention provides a
20 system for analysing a computing system comprising
determination means arranged to determine a dependency
between a first and a second system resource performance
characteristic in a computing system, the determination
25 means further comprising:

data gathering means arranged to provide data values
for the first performance characteristic and the second
performance characteristic of the computing system; and

computational means arranged to apply a mathematical
30 algorithm to derive a correlation value between the first
and second characteristics,

wherein the correlation value provides an indication
of the relative association between the second
characteristic and the first characteristic.

In a fourth aspect, the present invention provides a
35 computer program arranged, when loaded on a computing
system, to implement the method of a first aspect of the

invention.

In a fifth aspect, the present invention provides a computer readable medium providing a computer program in accordance with a fourth aspect of the invention.

5 In a sixth aspect, the present invention provides a method of analysing a computer system to determine the cause of an intermittent system overload, comprising the steps of, providing data values for the first performance characteristic and the second performance characteristic
10 of the computing system, and applying a mathematical algorithm to derive a correlation value between the first and second characteristics, wherein the correlation value provides an indication of the relative association between the second characteristic and the first
15 characteristic.

In a seventh aspect, the present invention provides a method of ameliorating the need to monitor multiple system characteristics by determining a subset of performance characteristics which particularly impact on the
20 performance of a given computing system, comprising the steps of, providing data values for the first performance characteristic and the second performance characteristic of the computing system, and applying a mathematical algorithm to derive a correlation value between the first
25 and second characteristics, wherein the correlation value provides an indication of the relative association between the second characteristic and the first characteristic.

In an eighth aspect, the present invention provides a
30 method of analysing a computing system to determine problematic characteristics of the computing system to reduce the number of characteristics which require further analysis, comprising the steps of, providing data values for the first performance characteristic and the second
35 performance characteristic of the computing system, and applying a mathematical algorithm to derive a correlation value between the first and second characteristics,

wherein the correlation value provides and indication of the relative association between the second characteristic and the first characteristic.

5 Detailed Description of the Drawings

Features of the present invention will be presented in the description of an embodiment thereof, by way of example, with reference to the accompanying drawings, in
10 which:

Figure 1 illustrates a general purpose computing system which may be used to implement the present invention.

15 Description of the Preferred Embodiment

At Figure 1 there is shown a schematic diagram of a computing system 10 suitable for use with an embodiment of the present invention. The computing system 10 may be used
20 to execute applications and/or system services such as deployment services in accordance with an embodiment of the present invention. The computing system 10 preferably comprises a processor 12, read-only memory (ROM) 14, random access memory (RAM) 16, and input/output devices
25 such as disk drives 18, keyboard 22, mouse 24, display 26, printer 28, and communications link 20. The computer includes programs that may be stored in RAM 16, ROM 14, or disk drives 18 and may be executed by the processor 12. The communications link 20 connects to a computer network
30 but could be connected to a telephone line, an antenna, a gateway or any other type of communications link. Disk drives 18 may include any suitable storage media, such as, for example, floppy disk drives, hard disk drives, CD ROM drives or magnetic tape drives. The computing system 10
35 may use a single disk drive 18 or multiple disk drives. The computing system 10 may use any suitable operating systems, such as Windows™ or Unix™.

It will be understood that the computing system described in the preceding paragraphs is illustrative only, and that an embodiment of the present invention may be executed on any suitable computing system, with any
5 suitable hardware and/or software.

In one embodiment, an embodiment of the present invention is implemented as a software module 22 which interacts with a database 32, arranged to be executable on the computing system 10.

10 An embodiment of the present invention provides a method of displaying, for every system performance characteristic selected for display or analysis, a list of other highly-correlated system characteristics. In one embodiment of a method in accordance with the present
15 invention, the method comprises the steps of:

1. at every sampling time, the values of all characteristics are collected
2. the correlation coefficient (using a Pearson methodology described hereinafter) between each two
20 characteristics is computed
3. when a characteristic is selected by the system administrator (for display/analysis), the selected characteristic and a list of characteristics having the highest correlation coefficient with regard to
25 the selected characteristic are displayed. The correlation coefficient is a numerical indicator (normalised to a value between 0 and 1) which describes the influence two characteristics have on one another. For example, a correlation coefficient
30 of 0.9 indicates that the two characteristics are highly dependent on each other, whereas a correlation coefficient of 0.1 indicates that the two characteristics have little influence on each other.

The aforementioned list of highly correlated
35 characteristics provides the system administrator with a basis for selecting and more closely examining other performance characteristics which may be of interest.

For example, after selecting disk usage of an overloaded disk, an embodiment of the present invention can display other characteristics with high correlation coefficients. If one of the characteristics with a high correlation coefficient is, for example, the number of transactions executed (of a defined type), this may suggest that the specific transaction type is overloading the specific disk. This knowledge allows, the system administrator to initiate further analysis into the highly correlated characteristic, and corrective action may be taken.

An embodiment of the present invention provides better insight into the causes of system overload. Such insight may be difficult or impossible to obtain using a standard approach (such as calculating global averages of counter values or laboriously tracing application logic). In the abovementioned example, a computing system could be comprised of tens of disks and the application could have hundreds of transaction types, making any type of "manual" analysis difficult and prone to trial and error.

Use of a Pearson correlation coefficient as a measure of dependency provides a quantitative measure of the dependency level and allows for relatively "cheap" on-line computation of coefficients. That is, an embodiment of the present method may be utilised for on-line display, in addition to off-line analysis, since the calculation of the coefficient is not computationally intensive.

Furthermore, there is a reduced need to have a comprehensive knowledge of system architecture. Whilst the system administrator requires rudimentary knowledge concerning the computing system, the correlation coefficients may be used as a basis for determining problem areas, thus reducing the number of system areas that need to be analysed to uncover possible influences on the selected (critical) performance characteristics.

Whilst the present invention finds an application in determining which performance characteristics are highly

correlated, useful information may also be derived from determining which characteristics are not highly correlated.

For example, a high correlation value of the
5 utilization of one processor with the utilization of
another processor is normal on most computer systems. In
such a situation, the discovery of a lack of correlation
between processors may provide evidence of a problem.
Therefore, an embodiment of the present invention may also
10 be utilised to determine performance characteristics where
a low correlation is present between two separate
performance characteristics.

An embodiment of the present invention will now be
described by reference to a simplified example.

15 In a contemporary computing system, various
characteristics and descriptors of the load, usage and
behaviour of a computing system are commonly collected.
The collection process is generally periodical. That is,
the underlying processes in a computing system are sampled
20 at defined time intervals (the interval size is generally
selected by the system administrator) and a set of data
values are recorded and/or displayed for each time
interval. For some systems, or some characteristics, such
collection occurs on a continuous basis, through the use
25 of a log file or files.

An example of such a system, is the WindowsTM
operating system, which contains a subsidiary software
application 'perfmon' - this application displays graphs
of user-selected system characteristics sampled every
30 second by default. Another example is 'sar' on UNIXTM
systems, which also displays data values for various
system characteristics.

The common aspect of such monitoring systems is that
the data produced can be modelled as a large rectangular
35 array (although such data is rarely displayed in this
manner). Each column of the array represents one system
characteristic (such as CPU utilization), and each row of

the array represents the value of all characteristics at a given time. The table below shows an example of such a view of the data:

5 Table I: Example table of system characteristics

	time	cpuUtil	dsk1Util	interrupts/s	...	sysCalls/s

	10:32	.94	.35	111322	...	23423
10	10:37	.14	.54	234234	...	34223
	10:43	.34	.34	445345	...	97887

Table I is merely an example of the type of data
15 values which are collected and should be considered to be
illustrative and not definitive of the type of data
collected by a computing system. The utilisation variables
(e.g. cpuUtil and dsk1Util) are values which are
normalised to a value in the range between 0 and 1, 0
20 indicating that no resources are being used, and 1
indicating that the resource is being fully utilised. In
practical situations, the table may contain hundreds or
thousands of variables (columns) and thousands to tens of
thousands of rows (data samples).

25 A method in accordance with an embodiment of the
present invention computes correlation coefficients
between all the columns in the table. The correlation
coefficient between any two columns of data x and y is
defined as:

$$cor(x,y) = \frac{\sum ((x_i - x_{mean})(y_i - y_{mean}))^2}{\sqrt{\sum (x_i - x_{mean})^2 \times \sum (y_i - y_{mean})^2}}$$

30 A more detailed description of the meaning and usage
of the Pearson correlation formula can be found in many
texts on statistics. For example, see **Bhattacharyya, G.K.,**
and R.A. Johnson, *Statistical Concepts and Methods*, New
York, John Wiley, 1977.

5 System administrators are able to obtain information
on how many, say, interrupts per second a computing system
is performing. However, the system administrator does not
know why an event occurs. To understand why an event
occurs, a system administrator requires good system
10 knowledge, experience, data hunting skills and some luck.

Utilising an embodiment of the present invention, a system administrator can list, for each system characteristic, any other highly correlated system characteristics. This provides the system administrator with further information on the behaviour of a computing system.

An embodiment of the present invention will now be described with reference to three examples from a real, though very small, system - with 132 variables (columns), each variable representing a different system characteristic and 3925 samples (rows) each sample representing the usage of each characteristic during a defined time interval (say, per second).

25 Firstly the performance characteristic 'interrupts per second' are selected and, applying the Pearson correlation coefficient formula to determine the performance characteristics with highest correlation coefficients, the following list is obtained:

30	BASE: "X..ACUS.5085R.Processor..Total..Interrupts.sec"	
	recentIo	0.69
	X..ACUS.5085R.PhysicalDisk.0.C...Disk.Transfers.sec	0.69
	tot.recentIoPerTx	0.61
	X..ACUS.5085R.PhysicalDisk.0.C.....Disk.Time	0.59
35	X..ACUS.5085R.PhysicalDisk..Total....Disk.Time	0.49
	X..ACUS.5085R.PhysicalDisk..Total..Avg..Disk.Bytes.Transfer	-0.25
	tot.runTime	-0.20

The first line in the list represents a particular characteristic, which has been dubbed the "base" characteristic. In this case, it is the total interrupts per second for a processor. The subsequent lines in the list represent further characteristics and associated correlation coefficients (which have been computed by computing the Pearson correlation coefficient between each of the further characteristics and the base characteristic).

When examining the list, a system administrator may suspect that interrupts are closely related to various occurrences on physical disk 0, as variables related to disk number '0' are highly correlated with the number of interrupts.

In a second example, the system administrator may be interested in CPU time. Utilising an embodiment of the present invention, the following list of highly correlated performance characteristics is generated.

BASE: "recentCpu"	
X..ACUS.5085R.Processor..Total....Privileged.Time	0.86
prc.sqlservr	0.51
X..ACUS.5085R.System.System.Calls.sec	0.42
prc.System	0.42
tot.tot.rt	-0.19
tot.recentCpuPerTx	0.18
prc.java	0.14

From the generated list, it is apparent that high CPU usage is related to use of privileged time and the SQL server process.

In a third example, a system administrator may be interested in an SQL server process. A generated list of the processes which are highly correlated to the SQL server process produces the following list:

BASE: "prc.sqlservr"

tot.recentTx	0.64
cCI	0.63
tot.tot.rt	-0.61

5

In this example, the SQL server process usage is closely related to transactions in general (as is expected) but the CI transaction in particular (which may be unexpected). Furthermore, the high usage of the SQL server process occurs at a time when the response time is low.

Therefore, provided with this information, the system administrator can investigate the CI transaction to determine whether it should be modified and/or re-written to improve performance.

These three examples illustrate the advantages of an embodiment of the present invention. An embodiment of the present invention provides significant insight into the dependencies between various system characteristics.

Modifications and variations as would be apparent to a skilled addressee are deemed to be within the scope of the present invention.